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A comprehensive review of bio-diesel as alternative fuel for compression ignition engines

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ABSTRACT

In the wake of oil crisis, the world is looking for the alternative source of energy where bio-diesel came into play as an attractive renewable alternative fuel. However, it was realized that extensive utilization of bio-fuel would tax the food chain and could lead to food shortages. So, the use of a blend of bi-fuel with conventional fuel was suggested to balance its usage which still could provide beneficial green house effect. In the hot and cold climate bio-diesel cannot conveniently replace fossil fuel but in the controlled environment with modified combustion equipment, bio-diesel can be used as an alternate fuel. Having lower heating value, bio-diesel is consumed more in comparison to the fossil diesel fuel. Bio-diesel also generates more NO_x emission, which is an adverse environmental pollutant. The raw material source of bio-diesel limits food growing ground which is ultimately becoming a great concern. A dilemma of using bio-diesel as an alternative for mineral fuel has raised a concern about environment, engine performance and involved costs these have to be investigated in depth to provide a recommendation.

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1. Introduction

Oil crisis in 1970 had influenced many countries to consider alternative fuels for replacement of fossil fuel. The National Alcohol Program (PROALCOOL) in Brazil was accomplished by implementing product stimulation, distribution and also by use of ethanol fuel from sugar cane [1]. To aid this program, the car manufacturing industry designed the specific engines for ethanol fuel. In 1986, this program established a landmark, when ethanol-fuelled automobiles reached 96% of the market shares in Brazil. In 1989, the interest to ethanol vehicles and flexible-fuel were lost due to enhancement of ethanol fuel cost, which ultimately failed to provide advantages to the consumers [1,2].

Brazil in 1990 experienced increase of vehicle import due to the lower import tax. The modern production strategy encouraged the local automotive enterprise to involve in continuous improvement and produce new products. Government encouragement for manufacturing small engines powered by cheap fuel turned Brazil into the one of major automobile manufacturers. Recently, continuous analysis in global arena has developed the flexible fuel engines that might run with any concentration of gasoline and ethanol blend. Automobiles, which can run with the variable fuel engines, attract many customers due to the possible ways to make a choice from gasoline and ethanol in accordance to the price and availability [1,3].

Bio-fuel is actually known as a renewable energy, which is produced from alternative renewable energy materials. Other bio-based renewable fuels systems have various ecological drawbacks. Biomass from agricultural resources is comparatively land intensive, and runs the risk of water resources pollution from pesticides and fertilizers which are normally needed to add to the land to enhance plant growth. Many scientists have observed this conundrum and also have tried to investigate bio-ethanol programs to explain their sustainability in the environment. With sufficient efforts researchers have discovered bio-fuels which could provide sustainable objective for environmental transportation. A number of articles were dedicated to ethanol alone and outlined typical undesirable environmental issues [4,5]. Alternative reviews on bio-fuels of many types and noted many favorable aspects for ethanol along with caution regarding many potential adverse environmental impacts [6] are highlighted. Different studies were conducted in the United States particularly on corn-to-ethanol route and finally inferred that the environmental sustainability is a great concern [5,7–9].

However, the question of problem of sustainability is quite complex, which encompasses environmental and human health along with societal issues. The attempts to provide solution a widen perspective is needed to prevent changing issues from one to different spot [10]. Many researchers have mentioned that these systems of liquid bio-fuel production, both projected and current could be sustainable if it is eco-friendly in nature [5].

The most prevalent bio-fuels, like biodiesel from vegetable seeds and ethanol from wheat, corn sugar beet, are produced from food plants, which require the rich agricultural land for growth [11–13]. Currently critical issues are dealing with the impact on global food supply. Fuel vs. Food could become a problem with the danger of diverting crops farmland for producing liquid bio-fuels, which will be detrimental to the world food supply. There are differences in opinion concerning how important this could be, what the impact is, what it inflicting and what need to be done to alleviate this concern. Recently, the increase in world oil prices generated a serious concern towards improvement of the global bio-fuels production. Some products like sugarcane, vegetable oil and corn are going to be used either as feed, food, or even create bio-fuels. Vegetable oils can be a renewable supply to replenishable source of fuel having energy content near to the diesel fuel. In addition, intensive usage of vegetable oils could potentially result in important adverse issues like food shortage in developing countries. Forest resource, knowledge of agriculture science and appropriate technology could be prescribed as a solution for issues of world food resources [11,14,15].

Energy costs influence clients decision and behavior and have significant impact on economic development. The taxes on energy costs are needed to be definitely recognized from prices, contract markets, spot markets etc. Biomass fuel is one of the main exploited global renewable energy sources. Developing low cost and efficient methods for the process of biomass into liquid bio-fuels conversion is crucial for minimizing reliance on petroleum sources, increasing the employment of neutralizing carbon techniques, and improving rural profits [16,17]. Recently, grain-based vegetable-oil and their product ethanol are notably used as biodiesels which generate problems for the use of grains in the food chain [11].

The goal is always to supply cheap biomass to a stream which is accustomed to selection of chemicals, fuels and alternative materials which might be cost competitive to the regular products. The definition of liquid bio-fuel is noted as biomass-to-liquid fuel. BTLF can supply completely different renewable sources alternative to petroleum; on the other hand, it still incorporates a low quantity of petroleum in the blend. The main distinction between petroleum and bio-fuel feedstocks is the content of oxygen [18,19].

Biodiesel means any kind of equivalent between diesel and bio-fuel that typically derived from animal fats or seed oils [20–22]. Specifically, it can be employed as the fuel for some engines, or mixed with petroleum in diesel engines with no or few modifications. Biodiesel has developed a wide range of applications due to its environmental advantages [23,24]. The biodiesel price is usually the main obstacle for it commercial usage. The used cooking oils could be a raw material where nonstop transesterification method and recovery of the best quality of glycerol as a biodiesel by-product could be a primary choices to reduce the cost of biodiesel [11,13,25,26].

The biomass thermochemical conversion processes are globally endothermic, and the required heat is supplied by solar energy [11,27]. However, if additional energy is provided from other renewable resources like wind, then the additional biomass carbon could to be changed to the liquid fuel [28,29]. Solar energy can possibly supply a few percentages of the thermal energy of bio-fuel plants. A test of direct focused radiation in biomass reactors has introduced many challenges. Solar radiation energy can be stored and utilized for the temperature levels required in processing of biomass. An operating fluid might transfer heat for processing of bio-fuel if needed. However, by adding energy from wind and solar sources, the energy requirement for bio-mss processing could be retarded [27,30,31].

2. Bio-diesel

Bio-fuel or bio-diesel is usually identified as ester-based fuels produced from animal fats or from vegetable oils by using an

Nomenclature

BSFC	Brake specific fuel consumption
BTLF	biomass-to-liquid fuel
Btu	British thermal units
PM	particulate matter
HC	hydrocarbon
CD	carbon deposit
CI	compression-ignition
CNG	compressed natural gas
D	day
DI	direct fuel injection
DMF	dimethylformamide
EIA	energy information administration
EPA	US Environmental Protection Agency
EUDC	extra-urban driving cycle
GHG	green house gas
h	hour
HHV	higher heating value
HOME	Honge oil methyl ester
IDI	indirect fuel Injection
IJ	injector
JOME	jatropha methyl ester
kW	kilowatt
LHV	lower heating value
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MOEE	Ministry of Energy and Environment
NA	naturally aspirated
NEDC	New European driving cycle
PROALCOOL	National Alcohol Program
SI	spark-ignition
SOF	soluble organic fraction
SOME	sesame oil methyl ester
TU	turbocharged
THC	total hydrocarbon emissions
UDC	urban driving cycle
USDA	United States Department of Agriculture
VOME	vegetable oil methyl ester
WC	water-cooled

effective transesterification method. The technique of using vegetable oil as a possible engine fuel was originated by Rudolf Diesel (1858–1913) who promoted the primary engine and ran it with vegetable fuel. Vegetable oils are necessary energy sources, though typically vegetable oils produce varied issues in engine elements. This downside is occurred due to the present molecular and volatility structure which also caused higher viscosity in comparison to diesel fuel [32–34]. This undesired character is often removed from bio-diesel by using various chemical methods like catalyst-free method, supercritical and transesterification of vegetable oils. As a result of this technique properties and molecular structure of vegetable oil is modified to establish fatty acid methyl esters, which is commercially called as bio-diesel fuel. Bio-diesel carries 4.5 units of energy against each unit of fossil fuel [35,36]. Besides this, bio-diesel is safer, biodegradable and nontoxic in nature [34].

Bio-fuels can provide a clean and renewable energy, so they have gained an increased attention for becoming eco-friendly and renewable fuel to support today's energy requirement [37]. A mandatory manufacturing policy could be a great deal of awareness by advertising the economic benefits of transition to bio-fuel. The technology of bio-fuel is driven by its production requirement which is also govern by political will such as the case of natural gas and oil [38].

Currently, some economic experiences and cost of technology of bio-fuel energy have wide applications neither in the richest countries nor in the poorest countries. Developed countries are involved in bio-fuel development and analysis, particularly through the international programs and collaborations, which might facilitate the development of newest technology for bio-fuel production once they turn into competitive stages. Currently, an important challenge faced by the developing countries is the method of investment on bio-fuel development and analysis to the bio-fuel economy transition. Developing countries need to be encouraged towards use of bio-fuel in industrialized zones, since they are generally suffering from their economies and the pollution trend. International organizations have a very crucial role in assisting countries for making an industry-based policy about bio-fuel and the clean energy systems [39]. International organizations should offer the developing countries economic support for capital investment in transition to bio-fuel [11,40,41].

Worth of bio-fuel shares of energy companies are increasing with the implementation of fuel cells for renewable energy supply. The strategy of renewable energy improvement embodies the thought of the inter-linkage and also the balance between social, environmental and economical factors. European Countries are introducing policies on different bio-fuels markets [42,43]. The marginal producer is dependent on the bio-fuels policy stances. Bio-fuel costs must not be used as an anti inflationary device [44].

For the simplicity of study bio-fuels might be categorized into four groups depending on the production technologies. Categorization of bio-fuels is dependent on the technology of production as enlisted in Table 1. The first-generation of bio-fuels seems not sustainable as a result of potential focus on food production. Second generation of the bio-fuels got a chance to develop the advantages of eco-friendly fuels as produced in addition to hydrothermal and pyrolysis liquefaction. Fischer–Tropsch and alternative catalytic procedures are attempted to produce additional advanced fuel, on which the future sustainable society will probably be dependent [45,46].

A number of studies have pointed out that the biodiesel [47–50] could be promising alternate fuel for diesel engines. Biodiesel is non-toxic, biodegradable, oxygenated and sustainable product [50]. The emission of biodiesel burning holds reduced

Table 1
Biofuels classification on different generation technologies [11].

Generation	Feedstocks	Examples
First	Sugar, starch, vegetable oils or animal fats	Bioalcohols, vegetable oil, biodiesel, biosyngas, biogas
Second	Non food crops, wheat straw, corn, wood, solid waste, energy crop	Bioalcohols, bio-oil, DMF, biohydrogen, bio-Fischer–Tropsch diesel
Third	Algae	Vegetable oil, biodiesel
Fourth	Vegetable oil, biodiesel	Biogasoline

range of HC, CO and PM, due to high oxygen content in it. However at the same time it produces larger NO_x emissions. Burning of pure biodiesel produces about 10% more NO_x compared to the petroleum-based diesel [50–54]. To reduce this undesirable pollution, researches are under progress to decreasing NO_x emission while biodiesel is used. Szybist, Simmons [55] have investigated this issue by modifying the timing of ignition delay along with the usage of biodiesel at different bulk modulus which is responsible for decreasing NO_x emission [55]. The policy of engine running guideline is unable to provide satisfactory outcomes of optimizing biodiesel engine emissions [56]. Leung et al. [56] suggested to employ a multi parameter adjustment for minimizing HC, NO_x and PM emissions [56]. Fernando, Hall [57] pointed out that the major cause of NO_x emission is controlled by the thermal NO_x mechanism; therefore, NO_x can be reduced by the use of water injection, ignition timing retardation or exhaust gas recirculation, which may cause decrease in flame temperature [50,57].

However, these types of strategies usually deteriorate engine performance. The emulsification strategy is additionally being used for minimizing NO_x emission and also to support the combustion performance for fossil fuels [58]. Consequently, the NO_x component of biodiesel emulsion is curbed in a biodiesel engine. Masjuki et al. [59] have analyzed the IDI engine performance by using palm oil methyl ester emulsions containing 5–10% of water by volume. The effects of noted emulsification was successful in minimizing the emissions of GHG, HC and soot and extending the service life of lubricant oil, and enhancement inhibition of the anti-wear engine components characteristics.

Kerihuel et al. [60,61] employed animal fat and ethanol emulsions into a diesel engine and examined the dominating parameters, formulation and engine performance [50]. They observed that the ethanol animal fat emulsion increases efficiency along with minimizing the emission of soot, HC, NO_x and CO at high engine loads. However, many studies have been designated for different fuels and for diesel engines but almost no knowledge are obtainable from the research about ethanol–biodiesel–water micro-emulsions in diesel engines. Therefore some research were designed to evaluate the combustion, efficiency and emissions of a 1-cylinder diesel engine running on ethanol–biodiesel–water micro-emulsions, and also to match the results with those of operating on neat bio-diesel [50,62].

It is important for a fuel to appear in the energy sources and emit less GHG and become a more secure fuel. Bio-diesel is an eco-friendly fuel for different consumers and a sustainable fuel in the global fuel field. Continued and growing usage of petroleum and its limited reserve enhanced the bio-diesel production, which is also desirable for its clean emission characteristics. Considering all environmental and economic advantages, output of bio-diesel is increasing rapidly as an alternative to petroleum diesel fuel all over the world [34].

A diesel engine requires a stable operating fuel, clean burning and to perform well within different restricted conditions. Bio-diesel satisfies these targets in any unmodified CI engine [34]. Bio-diesel physicochemical properties are coming from different sources like viscosity, cetane number, density, oxygen content and warmth worth greatly effect on the emissions characteristics and engine efficiency. Bio-diesel properties are dependent on the sources, like rapeseed, animal fats or soybean [33,34]. When working with bio-diesel (B100) or blends of bio-diesel (B5, B10, B20, B50) it is strongly suggested [34] that the blend should meet the specific standards for mixing with petroleum diesel, considering freezing and corrosive properties, storing of bio-diesel.

Diesel engines are a significant source of air pollutions and are well known to have an influence on overall greenhouse gases and human health [34]. The Australian State and Territory Governments and National environment Protection Council have considered a National Environmental Protection measure for ambient air quality [34]. Several studies have made an effort to examine the engine performances such as emissions and fuel consumption, torque and power, by using some types of bio-diesels. A performance comparison was conducted between two bio-diesels and the petroleum diesel [34]. These two bio-diesels are known as: type A – 80% tallow (sheep, pork and beef) and 20% canola oil methyl ester and type B – 70% chicken tallow and 30% waste cooking oil methyl ester were investigated. These bio-diesels were selected due to their easy availability and based on the need of clients (Kubota Engine manufacturer). Fuel varieties such as B100, B50, B20, B10 and B5 were analyzed (B20, 20% biodiesel+80% diesel; B40, 40% bio-diesel+60% diesel; B60, 60% bio-diesel+40% diesel; B80, 80% bio-diesel+20% diesel; B100, 100% bio-diesel) [34].

Approximately 38% of the petroleum products are used in the transportation market. To relieve the stress on petroleum diesel there are different fuels such as ethanol (E85 or E100), methanol (M85 or M100), CNG, LNG and LPG are being used as different fuel although these fuels do not appear to be a good choice for many engines. Bio-diesel is usually a beneficial fuel in comparison to other alternative fuels. The United States, some countries in Europe and a few Asian countries are using bio-diesel in maintenance equipment, transportation, generator, boat, etc. Recently, Germany is using the highest amount of bio-diesel products. The attention on bio-diesel production and analysis are rapidly increasing [63].

It is quite obvious that bio-diesel, is providing many blessings over petroleum fuel, like bio-diesel provides smooth engine operation by improving combustion characteristics and higher lubricity. Bio-diesel has a few disadvantages, for example bio-diesel is more expensive, weak cold flow properties which introduces restriction on usage of it in colder climate. Bio-diesel considerably decreases emission of GHG to the atmosphere by minimizing the HC, CO and PM discharges. However bio-diesel produces higher emission of NO_x, which contributes to GHG. Many researches are conducted to verify the bio-diesel potency related to these complaints [34]. Bio-diesel additives alter their combustion characteristics. The physical properties of bio-diesel are highly influenced by the fuel composition. Sweden is using metal oxides which could convert unrefined oils to bio-diesel cleanly and quickly but this procedure does not have the bio-diesel manufacturing steps such as conventional method [34].

As an alternative to diesel fuel (neat or even in blends), bio-diesel have the following benefits: [64] Its usage decreases the reliance on petroleum which will positively impact on the transportation market. Bio-diesel provides an immediate possibility to reduce the need of petroleum as it can be produced locally from waste oils, fats and oil seeds [34].

Table 2
Chemical and physical properties of different bio-diesels before and after transesterification process [34].

	Diesel	Canola	(After transesterification) Canola methyl ester	Palm oil	(After transesterification) Palm oil methyl ester	Beef tallow	(After transesterification) tallow methyl ester
Diesel kg/l @ 15 °C	0.83335	0.91	0.875–0.900	0.92–0.93	0.859–0.875	0.92	0.877
Cross calorific value (MJ/kg)	45.9	39.78	40.07	3.93	41.3	40.05	39.9
Viscosity (mm^2/s @37.8 °C)	3.86	37.7	3.5–5.0	36.8–39.6	4.3–6.3	N/A	4.47–4.73
Cetane number	40–58	39–44	49–62	42–62	50–70	N/A	58

Bio-diesel are produced by three different ways by means of acid catalyzed esterification directly from the oil with methanol and by applying transesterification process for conversion of the oil to fatty acids, namely base catalyzed transesterification of the oil with alcohol and then by acid catalysis to Alkyl esters. By transesterification of fat or oil with isopropyl, ethyl, methyl and different alcohols, however most of the bio-diesel analysis is concentrated on methyl esters [65]. The transesterification effect is influenced by different parameters like type of catalysts, glycerides to alcohol molar ratio, time and reaction temperature, free water and fatty acids content of animal fats or vegetable oils [25]. As co-product Glycerin could be coming out from transesterification procedure, which can be used in toothpaste, paints, cosmetics, pharmaceuticals and various commercial functions. The biodiesel esters are indication of physical and some properties of fuel such as viscosity, acid value, density, pour point, cloud point, iodine value, volatility and the gross heat of combustion. The transesterification process might change the properties of the animal fats or seed oils significantly. Table 2, represent the comparison of the chemical and physical properties of beef tallow, palm oil and canola oil and their methyl esters (bio-diesel) [66]. The density of the bio-diesels provides improvement over petroleum diesel (Table 2). Subsequently, the fuel consumption of bio-diesel is predicted slightly higher [34]. Furthermore, bio- diesel fuel made of beef tallow has the highest consumption among the three bio-diesels due to the higher density. The important bio-diesel properties are its higher cetane number and high lubricity [34].

The higher lubricity should contribute to a smoother running of engine and less engine wear. Higher cetane number usually supplies a shorter ignition delay time in diesel engine because the engine could perform smooth operation with nice cold start behavior and at low noise and additionally provide greater fuel economy and power. Although low cetane number fuels could generate increased exhaust gas emissions and inclined to engine knocking due to incomplete combustion [67]. Palm oil bio-diesel fuel in the engine is more effective than bio-diesel produced from canola oil and tallow. The energy content (gross calorific value) of biodiesel is less than petroleum diesel. This is obvious that the bio-diesel operated engine provides lower power level or enhances fuel consumption in comparison to diesel fuel and among the different types of bio-diesels tallow methyl ester provides less power or high fuel consumption by the engine [34]. This power reduction is normally about 5–10% which is determined by different engine loads and speeds, different types of bio-diesels [68]. The bio-diesel heating value is around 10% less than petroleum diesel, which causes the higher brake specific fuel consumption. Normally, diesel engines are allowed to run at different blend of petroleum fuel and bio-diesel [69].

2.1. Biofuel properties

Density, viscosity, heating value, flash point, acid value, pour point, cetane number, etc. are considered as the most important properties of a fuel for its application in engine. These properties indicate the quality of the fuel. Engine performance and emission are also directly related to these. There are different types of standard like ASTM, EN, ISO, etc. to define the limit of each of the fuel properties. Among them ASTM is the most widely followed standard. To meet the standard engine performance and emission, the value of the fuel properties must be in the range. Recently, blending is widely being used to improve biodiesel fuel properties. Sometimes biodiesel from two or more feedstock are blended to improve the properties. Use of more feedstocks can easily improve fuel properties rather than two because most of the important fuel properties like density, kinematic viscosity, oxidation stability, flash point, calorific value and cetane number vary linearly in case of multiple fuel blends [70]. Table 3 contains fuel properties of seven discussed vegetable based biodiesels.

2.2. Biodiesel production costs

Biodiesels are often manufactured by different processes. Fats and vegetable oils could be transformed into fatty acids and they are subsequently converted to esters. Fats or oils can also be changed into ethyl or methyl esters directly by using an acid or base to accelerate (catalyze) the transesterification reaction. As the catalysis is fast and thorough, a base catalyzation is preferred. Furthermore, it happens at lower pressure and temperature than those of different processes, contributing to reduced operating and capital losses for the biodiesel plant [71].

Bio-fuel prices additionally embrace a significant part which is contributed by bio-fuels production markets and influenced from food chain. Specially, the expense of making seed oil which produces biodiesel is covered by the expense of the oil and also the high-value usage competition such as cooking [72–74]. Table 4 shows estimated bio-fuels price [75].

The most prevalent means of manufacturing biodiesel is from vegetable oil or animal fat with methanol and in presence of sodium hydroxide (basically, called lye or caustic soda). This response could be a transesterification of base-catalyzed, which

Table 4
Estimated bio-fuels price (bio-fuels exclusive of taxes), (US cents/L) [11].

Bio-fuel	2006	Long term about 2030
Corresponding pre-tax price petroleum products	35–60	–
Bio-ethanol from sugar cane	25–50	25–35
Bio-ethanol from corn	60–80	35–55
Bio-ethanol from beet	60–80	40–60
Bio-ethanol from wheat	70–95	45–65
Bio-ethanol from lignocelluloses	80–110	25–65
Bio-ethanol from animal fats	40–55	40–50
Bio-ethanol from vegetable oil	70–110	40–75
Fischer-Tropsch synthesis liquids	90–110	70–85

Table 3
Fuel properties of ordinary diesel and common vegetable based biodiesel [70].

Properties	Kinetic viscosity 40 °C (cSt)	Density (kg/m^3)	Cetane number	Calorific value (MJ/kg)	Flashpoint (°C)
ASTM limit	1.9–6	–	47minimum	–	130 °C minimum
Diesel	2.5–5.7	816–840	45–55	42–45.950	50–98
Jatropha	3.7–5.8	864–880	46–55	38.5–42	163–238
Palm	2.95–4.92	843–890	49–65	38.73–40.39	135–259
Coconut	2.61–4.1	844–930	51–60	35–38.1	112–241.5
Cottonseed	4–4.9	874–885	51.2–55	40.32–42.73	70–110
Sunflower	4.5–5.9	877–882	49–52	39.7–40.56	85–178
Soybean	4.08–4.97	884–896	40–53	38.31–39.76	69–144
Canola or rapeseed	4.2–4.5	837–886	49–52.9	36.55–40.5	94–183

produces methyl esters and glycerine. If ethanol is substituted for ethyl esters, methanol and glycerine are produced, as methanol is more cost-effective than ethanol, so it is preferred [71].

The Energy information Administration (EIA) works on the costs for model the net feedstock impacts for costs of production, operating and capital costs. The feedstock expense for the grease or oil is the largest single element of biodiesel production costs. Yellow grease costs are less than soyabean oil and soyabean oil is used to produce varieties of products such as yellow grease, animal feed additive and for producing detergents and soaps. The most popular product yellow grease in the United States was produced 2.633 billion pounds from 344 million gallons (22,440 barrels per day) of biodiesel from 1993 to 1998. EIA, considers the usage limit of production of biodiesel from yellow grease to 100 million gallons annually (6523 barrels daily) [71].

The United states Department of Agriculture (USDA) predicted the effect on agricultural areas if the oil like soyabean is utilized as fuel: a reference case without and with a sustainable fuel standard case for production of biodiesel from soyabean oil. The predictions of EIA on soyabean oil costs provide an assumed amount of oil employed for production of biodiesel in every predicted year [71]. Table 5 is showing the bio-diesel production from soyabean.

For the alternative fuels in standard case, the quotient of the improvement in soyabean oil prices and also the amount of soyabean oil used for biodiesel production provides the rate of modification in soyabean oil costs depending on quantity of soyabean oil input to biodiesel production. The most current baseline soyabean oil costs, assuming no biodiesel production, are extracted from the USDA [71].

The usage of energy for biodiesel production process, for each gallon is 38,300 British thermal units (Btu) and 0.083 kW h of electricity from natural gas. EIA refers the energy prices estimation as 18 cents per gallon in 2004 and 16 cents per gallon in 2005 and 2006. Modern biodiesel price estimation is $1.04 per annual gallon. EIA considers that the financial biodiesel plant generates annualized return of 10% over 15 years. The hypothetical income stream treating as an annuity over the 15 years, the capital expense estimation is $1.36 million annually, or 13.6 cents per gallon at full output [71].

The National Biodiesel Board states that the biodiesel produced from plants has dedicated a capacity of 60 to 80 million gallons annually (3414 to 5219 barrels daily). Additionally, the capability of 200 million gallons (13,046 barrels daily) can be obtained from oleochemical, like Gamble and Proctor. Biodiesel manufacturers can produce around 80 million gallons annually of worth just sufficient to cover variable prices. The capacity of the oleochemical industry is not going to return on-stream unless the expense of biodiesel is sufficiently high to attract methyl esters out of different uses. An evaluation of diesel fuel production price as sorted against feedstock is provided in Table 6 [71].

Biodiesel industry is currently holding excess production capacity. Petroleum refineries use over 90% of their capability, and extra capital assets are required to stay up for improving requirement for tightening and services specification for products. Soyabean is basically no sulphur oil biodiesel. Producers of soyabean biodiesel are under over load and they have made no additional investments to provide output of nearly 80 million gallons in 2006 and the years ahead. Comparison of between biodiesel costs, excluding capital and the petroleum diesel costs, including capital [71] are presented in Table 5.

Table 5
Use of soya bean oil for bio-diesel production (dollars/gallon) [71].

Marketing year	50 million gallons of soyabean oil used for biodiesel production	200 million gallons of soyabean oil used for biodiesel production
2004/2005	1.95	2.22
2005/2006	1.91	2.17
2006/2007	1.87	2.15
2007/2008	1.84	2.12
2008/2009	1.86	2.20
2009/2010	1.89	2.25
2010/2011	1.94	2.35
2011/2012	1.99	2.41
2012/2013	2.06	2.47

Table 6
Production cost for diesel fuel from feedback (dollars/gallon) [71].

Marketing year	Soyabean oil	Yellow grease	Petroleum
2004/2005	2.54	1.41	0.67
2005/2006	2.49	1.39	0.78
2006/2007	2.47	1.38	0.77
2007/2008	2.44	1.37	0.78
2008/2009	2.52	1.40	0.78
2009/2010	2.57	1.42	0.75
2010/2011	2.67	1.47	0.76
2011/2012	2.73	1.51	0.76
2012/2013	2.80	1.55	0.75
2013/2014	2.86	1.59	0.75

2.3. Biodiesel effect on engine

Effect of bio-diesel on several engine performance and emission are stated have systematically.

2.3.1. Engine power

Pure biodiesel effect on engine torque and power is presented in Table 7. 70.4% of researchers have agreed that the engine power can be dropped with biodiesel due to the LHV of the biodiesels

Table 7
Pure biodiesel statistics effects on engine emission and performances [90].

	Total number of references	Increase		Similar		Decrease	
		Number	(%)	Number	(%)	Number	(%)
Power performance	27	2	7.4	6	22.2	19	70.4
Economy performance	62	54	87.1	2	3.2	6	9.7
PM emission	73	7	9.6	2	2.7	64	87.7
NO_x emission	69	45	65.2	4	5.8	20	29.0
CO emission	66	7	10.6	2	3.0	57	84.4
HC emission	57	3	5.3	3	5.3	51	89.5
CO_2 emission	13	6	46.2	2	15.4	5	38.5
Aromatic compound	13	–	–	2	15.4	11	84.6
Carbonyl compound	10	8	80.0	–	–	2	20.0

[57,76–89]. However, the outcomes are noted with some fluctuations in the result [90]. Many researchers [57,76–89] have recognized that the power loss was less than the expected due to power recovery. The average torque and power values of WFOME was reduced by 4.3% and 4.5% respectively due to higher viscosity and density in comparison to diesel fuel [79]. Utlu at el. [79] also observed that the lower heating value diminishes about 8.8% in the bio-diesel fuel. The break torque of test engine was studied by Hansen et al. [82,91] by varying viscosity, density and heating value of the fuel. They observed that the break torque loss was 9.1% when B100 biodiesel was used as fuel instead of D2 diesel at 1900 rpm. Murillo et al. [81] studied the performance of biodiesel in a 3-cylinder, N/A, submarine diesel engine at full load. They have noticed that the power decrease was 7.14% for biodiesel in comparison to diesel. They have also recognized that the heating loss of biodiesel was 13.5% in comparison to diesel fuel [90].

In the similar effect of decreased heating value and also power loss were described in a few research works [89,92]. The performance of biodiesel from cotton seeds was examined by a few researchers. They have noticed that the power and torque are reduced by 3–6% by using pure biodiesel instead of diesel oil. They have also identified that the biodiesel heating value was 5% less than diesel fuel. However the researchers have identified the atomization behavior of the fuel responsible for loss of power rather than loss of heating value [90].

Biomass, when exposed to heat in the absence of oxygen (i.e., pyrolysis), it converts into liquid, solid char and gas products. The liquid product, known as bio-oil or pyrolysis oil, is usually brown, crimson, or black in color having a density of 1.2 kg/L. Bio-oil has water content of usually 14–33% weight which could not be simply removed by typical ways (e.g., distillation). HHV of bio-oil range is frequently 15–22 MJ/kg which is certainly below that of the typical fuel oil (43–46 MJ/kg), mainly attributable to the existence of oxygenated compounds in bio-oil [93]. For conveniently using biomass since the middle of 20th century, the researchers have been started to convert it into petroleum-like liquids [11].

As an example, Berl processed biomass with alkaline water at 500 K to generate a viscous liquid, which contains 75% heating value and 60% carbon of material [94]. The biocrude contains 10–20% weight oxygen and 30–36 MJ/kg heating value compared to <1% weight oxygen and 42–46 MJ/kg of heating value in petroleum [95]. The high oxygen content imparts lower energy content, lower volatility, poor thermal stability, higher corrosivness and tendency to polymerize after sometimes [96]. In comparison to bio-oil from pyrolysis, the biocrude are constructed from hydrothermal liquefaction having minimum moisture content and higher value and it also needs better capital prices and longer residence time. Typical hydrothermal liquefaction conditions changes from 550 to 650 K, 7 to 20 MPa, with liquid water and its effects happening for 10–60 min [11].

It has been noted that there seemed to be no essential difference in engine power between pure diesel and biodiesel [68,97–102]. As an example, Lin et al. [97] have demonstrated that the highest and lowest variations in engine torque and power at full load with 8 types of vegetable oil methyl ester (VOME) fuels and petroleum diesel. Qi et al. [99] have mentioned about the trend, and said the engine delivers power on the basis of density of biodiesel and the volume, which is higher than diesel that needs to produce same heating value [90].

It was informed that there have been unexpected improvement in torque or power by using pure biodiesel engine [103,104]. Song and Zhang [103] have noticed that the torque and brake power of engine increased with increase in biodiesel blends percentage, thus the biodiesel consumption is increased. The higher oxygen content and injection timing will cause the advancement of a shorter ignition delay time. however it is incredible that the improved power of the pure biodiesel can achieve 70% of the with diesel fuel, as the outcomes may increase more with the viscous and more dense fuel mass from biodiesel and its blends [90].

2.3.2. Economy performance

Many scientific studies (up to 87.1%, Table 7) [57,76,78,79,81,82,84,85,88,89,97,105–125] agreed that the engine running with higher fuel consumption due to LHV of fuel. Most of the studies [57,78,88,105,111,112,123,126,127] have reported that the less amount of diesel fuel against biodiesel is due to the LHV. Armas et al. [116] have noticed that the brake specific fuel consumption of B100 biodiesel (having LHV, about 12.9% less than that of BP15) had increased around 12% in comparison to the BP15 while running a 2.5 L, TU and DI, common-rail diesel engine at 64 Nm and 2400 rpm. Hasimoglu et al. [112] achieved the upper BSFC 13% but LHV 13.8% for biodiesel in comparison to diesel on a 4-cylinder, DI and TU engine. Lin et al. [97] examined the BSFC of 8 different types of vegetable oil methyl ester in a 1-cylinder, 4-stroke, DI, WC engine. They found higher range of BSFC from 9.45 to 14.65% for biodiesel than that of diesel fuel, which refers the same result obtained in case of LHV range from 12.9 to 16% of these vegetable oil methyl esters [90].

Many researchers [76,84,85,121,124,125] have demonstrated that the increase of biodiesel fuel consumption ratio is more than LHV ratio. Luján et al. [121] noted that the variation in fuel requirement was 18.5% in mass between pure biodiesel and diesel. They have also noticed that the variation had decreased to 13.5% in volume due to high density of biodiesel. Labeckas and Slavinskas [76,124] informed that the pure biodiesel BSFC (LHV is lower than 12.5%) increased by 18.7% at 1800 rpm and 23.2% at 2200 rpm. They observed [76] that the raised BSFC was higher than 18% for B100 biodiesel in comparison to diesel however the decrease of heating value concerned only 8% for biodiesel [90].

Some authors [89,113,128] have informed that the raised fuel consumption was less than the biodiesel LHV. Gumus and Kasifoglu [128] have demonstrated that the BSFC for B100 was 4.8% higher than that of diesel fuel due to a higher viscosity and LHV of about 7.4% [90].

Table 8
Impact of engine exhaust on human health [135].

Exhaust emissions	Impact on health
PM	Lung cancer and cardiopulmonary deaths
NO_x	Irritate the lungs and cause oedema, bronchitis and pneumonia; and result in increased sensitivity to dust and pollen in asthmatics
CO	Its affects fetal growth in pregnant women and tissue development of young children. It has a synergistic action with other pollutants to promote morbidity in people with respiratory or circulatory problems
HC	Eye irritation, coughing and sneezing, drowsiness and symptoms akin to drunkenness. Some hydrocarbons have a close affinity for diesel particulates and may contribute to lung disease
PAHs	Eye and nose irritation, coughing, nausea and shortness of breath
Formaldehyde	Eye and nose irritation, coughing, nausea and shortness of breath

It has been reported by some authors [80,83,103,129–131] that the fuel consumption of biodiesel was decreased compared to diesel. Ulusoy et al. [129] have examined in a 4-cylinder, 4-stroke 46 kW diesel engine and informed that the frying oil biodiesel fuel consumption was 2.43% decreased [90]. Some researchers [132,133] observed no noticeable difference between diesel and pure biodiesel. Dorado et al. [132] have investigated waste olive oil biodiesel in a 3-cylinder 2.5 L engine with different testing models, and observed no significant variations in BSFC in comparison to diesel. It had been informed by Sahoo et al. [133] that BSEC is slightly higher for B100 at lower loads and stays same at higher loads [90].

2.4. Emissions of bio-diesel

Constituents of emissions like PM, NO_x, CO, HC and CO_2 of bio-diesels engine are discussed and stated in the following sections.

2.4.1. Impact of engine emissions on environment and human health

The emissions which are produced due to combustion of petroleum derived fuel have an adverse effect on environment and human health. It is reported by the unite nation intergovernmental panel that global warming is increasing due to the green house gas emission including methane, nitrogen oxides and carbon dioxides. Liaquat, Kalam [134] reported that if the average global temperature is increased by more than 2 °C, many people about hundreds of millions of people will lose their lives. Carbon monoxide (CO), hydrocarbon (HC) and formaldehyde (HCHO), Oxides of nitrogen (NO_x), particulate matter (PM) and organic gases other than methane (Non-Methane Organic Gases, i.e., NMOG) which are emitted from internal combustion engine has been identified as harmful to the human health and environment degradation. Table 8 shows the impact of exhaust emissions on human health.

2.4.2. Factors affecting engine emission

Both the regulated and unregulated emissions are affected by the following factors; biodiesel feedstocks (sources); contents of biodiesel, cetane number, advance injection timing and combustion, oxygen contents, engine load, engine speed, density and viscosity [135]. A summary of various reports regarding the factors which have effect on engine emissions such as NO_x, HC, PM and CO has been presented in Table 9.

2.4.3. Particulate matter (PM)

It can be overpowering debate (up to 87.7%, Table 10) that the usage of biodiesel rather than diesel causes the reduction of PM emissions [77–80,83,85,87,88,97,99–103,106–108,111,113,114,117,119,121–123,125,128–130,133,137,138,142,146,153–156,160–165]. Wu et al. [138] experimented the emission of five pure biodiesels on the Cummins ISBe6 DI engine with NA and TU, and observed that this biodiesels have decreased the range of PM emissions around 53–69% in comparison to the diesel fuel [80,116,151–153]. Armas et al. [116] have discovered that the raised value of PM was due to partially burned or unburned HC emissions. These HC can reduce and become absorbed on the PM surface, therefore resulted in increase of SOF and that is the important key of PM [94].

Lin et al. [97] also noticed that there is remarkable reduction from 50% to 72.73% in the smoke emission while investigated for eight types of VOME fuels in comparison to PD. Additionally, it was noted by some researches [78,99,107,122,129,153,165] that the PM value were decreased about 50% for biodiesel in comparison to diesel oil. Some researchers [166] have been observed the extreme PM reduction for biodiesel about 75–91%. A few researchers have observed totally same PM emissions for biodiesel in comparison to diesel fuel [167,168], occasionally they have also noticed a little increase in comparison to diesel fuel [76,116,140,169,170]. Armas et al. [116] mentioned that the increase of PM was due to partially burned or unburned HC emissions. These HC can be reduced and

Table 9
Factors affecting the engine emissions [135].

Factors	References for NO_x	References for CO	References for PM	References for HC
Biodiesel feedstocks	[68,97,136,137]	[122,136,138,139]	[139–141]	[137,138]
Contents of biodiesel	[81,118,128,137,142,143]	[76,81,142,144]	[77,83,85,142,145,146]	[131,141,146]
Higher cetane number	[54,80,141,147,148]	–	[103,145,149]	[150]
Advance injection timing	[122,137,141]	[84,116,151]	[54,78]	[78,116,146]
Higher oxygen contents	[124]	[109,114,118]	[152]	[153]
Engine load	[54,81,107,117,128,143,154]	[109,110,128,155]	[106,107,156,157]	[54,149,154]
Engine speed	[137,158]	[99,137,159]	[103,155]	–

Table 10
Overview of biodiesel engine durability and blends [90].

Content and feedstock	Ref. diesel	Engine tested	Operation conditions	Duration	Test results
20% rice bran oil	Conventional	4-cylinder, NA, WC, DI	Ten nonstop running cycles 1500 rpm	100 h	CD: significantly lower Wear: lower
20% linseed oil	Agricultural	1-cylinder, WC, portable	1500 rpm	512 h	Injector (IJ): no coking, no filter Plugging Wear: lower
100%, 15%, 75% palm oil	Conventional	4-cylinder, NA, WC, IDI, 1.8 L	2000 rpm	512 h	Wear: lower
100%, 50% soyabean oil	(No. 2EN 590)	TC, DI, 1.9 L	NEDC driving cycle	100 h	The reduction of wear with the increased content of biodiesel
100% wasted olive oil	(No. 2EN 590)	3-cylinder, WC, DI, 2.5 L	8–15 kW and 1800–2000 rpm	1350 kW, 750 kW	Wear: higher except piston
100% rapeseed oil	(No. 2EN 590)	6-cylinder WC, DI, 11 L	–	50 h	CD: similar IJ: cleaner than that of D2
100% mahua, karanja oil	High speed diesel	–	Static test at ambient temprature	300 D	No corrosion on piston metal and piston liner

absorbed on the PM surface, resulting to SOF increase, which could be the primary PM element [90].

2.4.4. NO_x

It had been noticed (Table 10) that about 65.2% researches believe that the NO_x emission increased by using of pure biodiesel [77,80,82,84,88,97,101,103–105,109,110,117,118,120–122,124,129, 142,143,151,154,156,159,160,164,165]. NO_x emissions increased 15% for B100 at enhanced load condition as the results of higher gas temperature in combustion chamber with 12% oxygen content in product gas [156]. Ozsezen et al. [78] have studied a 6-cylinder DI, NA, WC diesel engine and WPOME and observed that the NO_x emissions of the WPOME was increased by 6.48% and 22.13%, separately. Lin et al. [97] conducted research on eight types of VOME as stated earlier and discovered that employing VOME fuels in the diesel engine produce higher range of NO_x emissions which was increased from 5.58 to 25.97%, in comparison to PD. Obviously, it was observed no significant difference or small difference between diesel and biodiesel [100,171,172]. Researchers [100,172] have been mentioned about the similar NO_x emissions with biodiesel and diesel. Durbin and Norbeck [173] examined the pure biodiesel, diesel and 20% biodiesel blends in four different engines representing a large range of heavy-duty engines: DI and IDI, TU and NA. They observed no difference in emission of NO_x and figured that the gap was not significant. Wang et al. [171] have shown a similar conclusion after they researched on 35% blend of biodiesel from diesel and soyabean oil on different vehicles. About 29.0% of the researches [76,79,85,99,113,116,132,133,153,154,174] mentioned that biodiesel reduced the NO_x emissions. Puhan et al. [153] shown that the MOEE has reduced the NO_x emission around 12% in comparison to the whole load range of diesel fuel. Dorado et al. [132] observed 20% reduction of NO_x emission from wasted olive oil biodiesel with different eight mode cycles. The NO_x emission values were 970, 990 and 1000 ppm from three biodiesels JOME, residential and SOME severally, in comparison to 1080 ppm of NO_x obtained from diesel oil by running the engine at 80% load [140]. Additionally, the most researches [79,99,133,153,175] have shown that the biodiesel NO_x emissions decreased by no more than 5% [90].

2.4.5. CO

Many researches (84.4%) as shown in Table 10, obtained a benefit by replacing diesel oil by pure biodiesel and observed the emission of CO is reduced [76–79,81,84,85,88,98,99,101, 105,107,111,113–115,118,120,121,129,137,142,155,160,163]. Krahl et al. [176] discovered about 50% decreases of CO emissions by using oil biodiesel in comparison to ultra low and low sulphur diesel. Raheman and Phadatare [85] like some others observed high CO emissions reduction. They have found that CO emission decreased 73–94% for the karanja methyl ester (B100) and its mixtures (B80, B60, B40 and B20) in comparison to diesel oil. Also Ozsezen [78] have noticed that the reduction range of CO emissions was 86.89% and 72.68% for WPOME and they are available in plenty [90].

However, some study [79,84,99,111,114,129,138,153,161] have noticed less reduction. Puhan et al. [153] achieved the reduction of CO around 30% whereas Utlu and Koçak obtained 17.3% [79]. At the same time, Wu et al. [138] studied that 5 types of biodiesels as stated previously which reduced the emission of CO by the average range of 4–16%. However, several researches described that there is no reasonable difference in CO emissions between diesel and biodiesel [100,103]. This can be mainly related to low emissions [90].

Some researchers have noticed an important increase in CO emissions from pure biodiesel [121,122,126,140,177]. Banapurmath et al. [140] have studied the comparison of the CO emissions for HOME, SOME and JOME in a 1-cylinder, 4-stroke, WC, DI and CI diesel engine at 1500 rpm. CO values were 0.145%, 0.155% and 0.12% for HOME, JOME and SOME, in comparison to 0.1125% for diesel at 80% operating load. The CO emission from pure biodiesel separated from jatropha oil deteriorates [122], however there was a noticeable difference for that pure biodiesel from polanga and karanja oil. Specially, Fontaras et al. [126] described the usage of B100 and B50 which resulted CO increase over NEDC, in the order of 54% and 95%, respectively. The researchers with expertise on combustion have identified that the poor mixing and combustion are responsible for poor spray characteristic and the higher viscosity of the biodiesel [90].

2.4.6. HC

It was obvious that 89.5% (Table 10) HC emissions are reduced by pure biodiesel in comparison to diesel fuel [78,80,88, 97–100,103,104,107,108,115,118,129,154,160]. Wu et al. [138] mentioned that these 5 different types of biodiesel reduced HC emissions by 45–67% on the average in comparison to diesel fuel. Some scientists [78,80,107,153,155,176,178] observed similar reduction. In particular, Puhan et al. [153] have observed a 63% average reduction range of HC emissions for biodiesel compared to diesel oil. Alam et al. [179] noticed about 60% reduction in HC emissions from biodiesel regarding ULSD. However, the researchers have noted the low decrease [80,97,99,118,122,165] of HC in emissions. Lin et al. [97] observed that the THC emissions reduction varies from 22.47 to 33.15% for the 8 types of VOMEs as stated earlier. Sahoo et al. [122] have studied on different biodiesels from polanga, jatropha and karanja and their mixtures in comparison to diesel oil on a 3-cylinder, WC tractor engine during 8 mode cycle tests, and obtained the reduction of HC emissions by 20.73%, 20.64% and 6.75%, respectively while using the pure biodiesels instead of diesel oil. Obviously, many studies [124,167,180] have discovered that the diesel and biodiesel are similar in nature. An amazing trend represents the increase of THC emissions from biodiesel [126,140,169]. Kumar et al. [177] observed the increase of HC emission was about 10% from methyl ester of jatropha oil in comparison to diesel fuel. Fontaras et al. [126] have mentioned that there is an adverse effect on HC emissions on the legislated cycles like UDC, NEDC and EUDC from the use of biodiesel and about 58% enhancement of HC emissions are noticed by using pure biodiesel over the NEDC. Banapurmath et al. [140] have established that HC emissions with HOME, SOME and JOME were higher in comparison to the standard diesel fuel in a 1-cylinder, 4-stroke, WC, DI engine at 1500 rpm. They observed this trend in a relatively poor atomization and lower volatility status of biodiesels [90].

2.4.7. CO_2

Some researchers have studied CO_2 emission from biodiesel and stated that it could be as high as 23% [181]. Some authors [78,79,101,122,159] have reported that, biodiesel led to fewer CO_2 emissions in comparison to diesel oil on complete combustion from lower carbon to hydrogen ratio. Lin [158] used ASTM No.2D diesel for comparison of CO_2 emissions from 3 different types of biodiesels on the basis of CO_2 emission index which is defined as the CO_2 emission (%) divided by the equivalent fuel consumption rate (in units of g/h). He observed that the 3 specific types of biodiesel had lower CO_2 emission indices than the mentioned diesel. This is responsible for the low carbon content in biodiesel and lower elemental carbon to hydrogen ratio than diesel fuel. It was observed that CO_2 emissions increased [111,124,126,153,155,178] or kept similar [103,110] due to higher CO_2 emission from biodiesel as detected by some investigators [122,124]. It was inferred that these could be less concern as a consequence of recovery of Nature by utilizing CO_2 for nourishment of biodiesel crops. Researches [84,100] have investigated the

influence of biodiesel globally on the GHG throughout the life cycle of CO_2 emission. They have mentioned that the use of biodiesel could reduce 50–80% CO_2 emissions in comparison to petroleum diesel [90].

3. Impact of bio-diesel as an alternative fuel

Of the total global fuel energy demand about 67% is supported by fossil fuel and 33% is furnished by all the available renewable energy sources, like hydroelectric, wind, solar etc., targeting mainly the power generation market [182,183]. Current statistics says that the total reserves of fossil fuels are 260 billion cubic feet of natural gas and about 85 million barrels of oil daily and the amount of natural gas available for 64 years and oil for 40years [184]. Microorganisms of lipid-accumulating in nature such as microalgae, yeast and cyanobacteria could be used for biodiesel manufacturing. Solar energy as alternative source of power is being utilized by different means. Thus, energy from solar resource is used by plants for nourishment and grows seeds to produce oil for edible and energy source. Finally, it provides an energy change phenomena from solar to dense chemical form as biodiesel of all kinds [184,185].

In global positioning location 30 and 45° latitude the corn grows. North America (and, of course, a corresponding arc in the southern hemisphere) covers almost the whole region remaining under arc. 240 W/m^2 is the average power density of sunlight in these regions [186]. Adverse effect of weather is not being considered here and therefore it must be regarded as a maximum average. The plants collect light energy from the wavelength ranging between 400 and 700 nm of the incident sunlight representing 43% of the total solar energy arriving on the surface of earth [186,187]. Thus, the maximum power density of sunlight useful for photosynthesis is:

$$(240\ \mathrm{W/m^2}) \times 0.43 = 103\ \mathrm{W/m^2} \quad (1)$$

To enable cross-fertilization ear formation corn needs to be grown in rows and thus does not cover 100% of the available land. At best, about 80% land for the plant can be used for farming. Thus the growing plants can see the maximum solar power as:

$$(103\ \mathrm{W/m^2}) \times 0.80 = 82\ \mathrm{W/m^2} \quad (2)$$

The concept of using vegetable oil as fuel dates back to 1895 [188]. Some of the disadvantages of using biodiesel are listed below:

1. Slight degradation in fuel economy on the basis of energy (about 10 for pure bio-diesel).
2. In cold weather the density is more than diesel fuel, but may need to use blends in different condition of sub-freezing.
3. More expensive than diesel fuel due to less vegetable oil production [189].

Huntley and Redalje [188] reported that the average biomass energy production is 763 GJ/ha/year at Hawaii. 422 GJ/ha/year is the average oil yield estimated by the researchers, which is roughly 0.6% of incident solar energy, considering over 1200 gal of biodiesel per acre-year, representing far better than conventional oil bearing crops [184].

The total global energy demand is 13 TW/year (in 2000 predicted to rise to 46 TW in 2100), whereas the total incident solar energy is 178,000 TW/year, which is 13,500 times the total global energy demand. These information convince us to use solar energy systems and it is advantageous even in countries having poor irradiation [190].

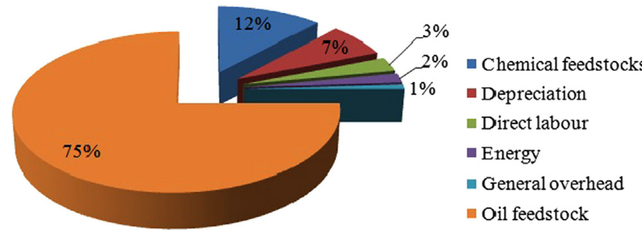

Fig. 1. General cost breakdown for production of biodiesel [135].

The algae production price ranges between 6.5 and 8 USD per gallon. By economic modeling reveals that algae cost is competitive to corn and sugar cane-based bio-ethanol [191]. Schenk, Thomas-Hall [182], stated that the fuel extracted from algae costs 39–69 USD per barrel as estimated by Schenk, Thomas-Hall [182] whereas the cost evaluated by others around 84 USD per barrel [182,184,192]. Solar energy can help to recover the energy needed to produce bio-diesel [193]. Making use of this resource, microalgae may have a profound impact on food and energy security, global warming and human health [192].

There are more than 350 oil-bearing crops recognized worldwide as potential sources for biodiesel production. The broad range of existing feedstocks for biodiesel production represents one of the most important advantages of biodiesel. According to some researches [135,194], feedstock acquisition currently accounts for over 75% of biodiesel production expenses as depicted in Fig. 1.

In general, biodiesel feed- stocks can be divided into four main categories as below:

1. Edible vegetable oil: canola, soybean, peanut, sunflower, palm and coconut oil.
2. Non-edible vegetable oil: Jatropha curcas, Calophyllum inophyllum, Moringa oleifera and Croton megalocarpus.
3. Waste or recycled oil.
4. Animal fats: chicken fat, pork lard, beef tallow and poultry fat.

Table 11 shows primary biodiesel feedstock for some selected countries around the world. The initial evaluation of the physical and chemical properties of edible and non-edible feedstocks is very important to assess their viability for future biodiesel production.

3.1. *Food price evolution*

Simulated value of actual demand for food crops as bio-fuel feedstock up to 2007 and bio-fuel growth in 1990–2007 are compared. It is observed that to meet the growing demand of bio-ethanol and bio-fuel the price of crop grain grown up from 2000 to 2007. The weighted average grain price is grown up to 30% compared to previous rate of increase due to the demand of bio-fuels and bio-ethanol during the stipulated time. Considering price impact on maize, the increased bio-fuel demand is estimated to account for 39% of the price hike. On the other hand increase in price of rice and wheat about 21% and 22%, respectively refers to increasing the bio-fuel demands (Fig. 2) [195].

3.2. *The freezing impact on bio-fuel production*

Rosegrant [195] has foreseen that with the cessation of bio-fuel production in 2007, the price for all crops in all countries used as feedstock will remain unhindered whereas the projected maize could have been declined by 6% within 2010 and 14% by 2015. Smaller price reductions are also expected for oil crops, cassava, wheat, and sugar (Fig. 3) [195].

Table 11
Current potential feedstocks for biodiesel production worldwide [135].

Country	Feedstock
USA	Soybeans/waste oil/peanut
Canada	Rapeseed/animal fat/soybeans/yellow grease and tallow/mustard/flax
Mexico	Animal fat/waste oil
Germany	Rapeseed
Italy	Rapeseed/sunflower
France	Rapeseed/sunflower
Spain	Linseed oil/sunflower Greece Cottonseed
UK	Rapeseed/waste cooking oil
Sweden	Rapeseed
Ireland	Frying oil/animal fats
India	Jatropha/Pongamia pinnata (karanja)/soybean/rapeseed/sunflower/peanut
Malaysia	Palm oil
Indonesia	Palm oil/jatropha/coconut
Singapore	Palm oil
Philippines	Coconut/jatropha
Thailand	Palm/jatropha/coconut
China	Jatropha/waste cooking oil/rapeseed
Brazil	Soybeans/palm oil/castor/cotton oil
Argentina	Soybeans
Japan	Waste cooking oil
New Zealand	Waste cooking oil/tallow

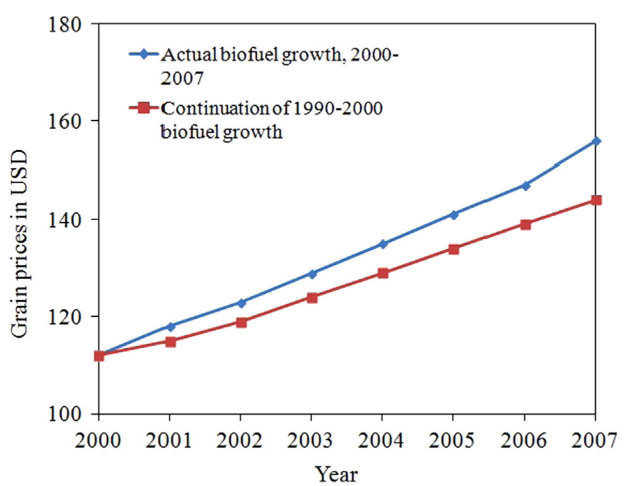

Fig. 2. Simulated real grain prices from 2000 to 2007 (USD$/metric ton) [195].

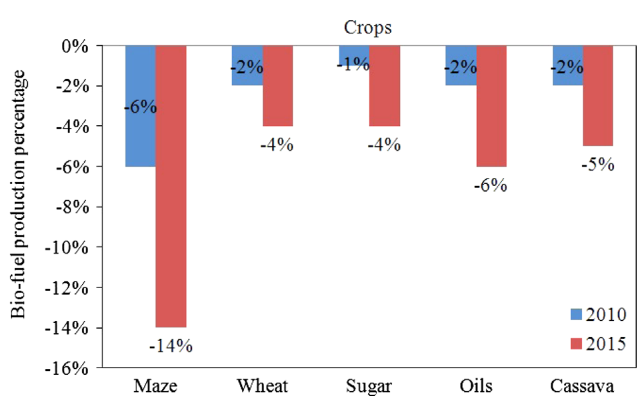

Fig. 3. Change in selected crop prices if bio-fuel demand for all crops was fixed at 2007 levels [195].

3.3. The elimination impacts on bio-fuel production

Considering no bio-fuel demands from food crops (or a global moratorium on crop-based bio-fuel production were imposed)

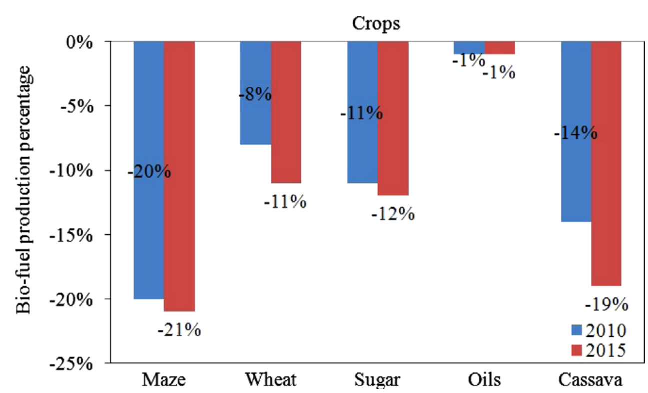

Fig. 4. Change in selected crop prices if bio-fuel demand is eliminated after 2007 [195].

after 2007, prices of key food crops would have dropped more significantly in order of 20% for maize, 14% for cassava, 11% for sugar, and 8% for wheat by 2010 (Fig. 4) [195].

4. Summary

Biodiesel is produced from renewable sources and it can play increasingly a major role in support of meeting energy demand in transportation systems although there have been inconsistent trends for the performances of biodiesel engine and different range of gases emission during varied biodiesel blends and operating conditions or driving cycles. Pressures on international grain marketing have influenced on prices during the past years. Due to the retarded grain growth and rapid growing demand for grains the price of biodiesel can be easily reversed. The global food economy is facing demand for food, feed, and fuel and also the future challenges of increasing land-use pressures and climatic changes. The agricultural productivity will have to grow significantly faster in the future than it had been in the recent past years. Lack of easy access to food will influence food prices, such as possible long-term illness, irreversible consequences for health, productivity, and well-being particularly if higher prices result in reduced food consumption by infants and preschool children.

If the current bio-fuel expansion continues, calorie availability in developing countries is expected to grow slowly which will lead to higher number of malnourished children, even though agricultural income would also accelerate.

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